1979

The Relationship of Root-pulling Resistance, Tassel Size, and Silk Delay with Yield in the F1

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THE RELATIONSHIP OF ROOT-PULLING RESISTANCE, TASSEL SIZE, AND SILK DELAY WITH YIELD IN THE F_1 HYBRIDS OF 12 CORN (*Zea mays* L.) INBREDS.

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in Agronomy,
South Dakota State University
1979

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. D. B. Shank
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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. D. B. Shank and Mr. J. R. Jenison for their help and guidance during this investigation; to Dr. W. L. Tucker for his aid in the analysis and interpretation of the data; and to the USDA Northern Grain Insects Research Laboratory for the use of their root-pulling apparatus.

D.W.P.

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INTRODUCTION

One of the major objectives of commercial and publicly supported plant breeding programs is the selection of corn lines which exhibit superior yielding ability under stress conditions. To accomplish such a goal, various plant characteristics have been examined. For example, strong, high volume root systems have been selected to increase resistance or tolerance to corn rootworm feeding and root rot. Large tassels are also selected, whether consciously or not, to maintain good pollen production over a long period of time under dry or other adverse conditions. Similarly, many researchers stress selection of lines which exhibit a short period of time between the onset of pollen shed and the appearance of the silks (silk delay).

By changing these plant characteristics, will we counteract our goal? For example, by selecting for a stronger, higher volume root system for the plant to maintain can it still produce a superior yield? In effect, is there an optimum root size beyond which the trait may serve to reduce yields? This point becomes particularly important when the plant is subjected to stress conditions.

Recent research has not attempted to deal with this question. In light of the continuing selection for increased root volume and tassel size, we should further investigate the effects of such selection pressures on our goal of yield. The objective of this experiment is to investigate the relationships which exist among root volume (as estimated by root-pulling resistance), tassel size, silk delay, and yield, particularly when the plant is subjected to stress.

REVIEW OF LITERATURE

In an effort to improve the overall yielding ability of corn, experiments have been conducted to identify plant characteristics which aid in the plant's ability to withstand stress conditions caused by disease, insects, and environmental conditions such as drought. Experiments of this type have resulted in suggested superior plant types for traits such as root volume and flowering characteristics which breeders have selected for in their programs.

Over the years, a great deal of work has gone into the understanding of the corn root system. Variations among the root systems of corn lines were noted by several investigators. In 1926, Smith and Walworth (36) found a great deal of variation in seminal root numbers among inbred lines. Mengelsdorf and Goodsell (23) however, found that this characteristic could not be correlated to yield and should not be used as a selection criterion.

In 1935, Weihing (41) reported that corn varieties could be divided into 3 classes based on the vegetative growth produced. He found that those corn varieties which produced larger amounts of vegetative growth had greater root volume and root dry weight than those varieties exhibiting less vegetative growth. Harvey (14) found that the top-root ratios of corn differ significantly among inbred lines. Shank (35) confirmed Harvey's study with his observations of 21 inbred corn lines. Holbert and Koehler (15) found further variation in the form of root numbers exhibited in corn inbred lines. Spencer (37) confirmed the presence of root number variation as well as the root dry weight variation among varieties reported by Weihing (41).

In a report on the morphology and growth of two inbred lines of maize, Whaley (42) reported that one line showed a significantly higher rate of root development during early growth stages. This resulted in a larger root system than that of the inbred which developed more slowly. Andrew and Solanki (3) concluded that inbred corn lines exhibiting lower top-root ratios produce larger root systems while inbreds with higher top-root ratios have smaller root systems. This study also found that the proportion of the root system accounted for by the seminal roots at 477 degree-days (approximately 21 days) after planting is inversely and significantly related to the volume of the entire root system at 613, 716, and 815 degree days.

The results of these investigations established the diversity which exists among the root systems of different corn lines and indicated that the above-ground plant characteristics may be related to these root characteristics. This information could be useful only when the investigator decides which root types are superior for his specific objective and how plants or lines with such root types can be selected efficiently. Several methods of selection for root traits have been devised and used successfully. Root-pulling resistance (the force required to remove a corn root system vertically from the soil) has been used to a great extent. Other methods have included root volume used by Musick, Fairchild, Fergason, and Zuber (25) and Zuber (44), root clump weight used by Thompson (39) and Zuber (44), and root dry weight used by Norden (29,30). Experiments involving more than one method often showed strongly correlated results obtained by the different methods.

Holbert and Koehler (15) provided some of the first data on the use of root-pulling resistance. They found a great deal of variability in the root-pulling resistance exhibited by different inbred lines and suggested that root-pulling resistance may be directly related to root number and root rot susceptibility. Wilson (43) reported that lines exhibiting the greatest root-pulling resistance showed the greatest lodging resistance. Both of these studies suggested that the characteristic of root-pulling resistance is related to other root characteristics and holds promise as a criterion for selection of stronger root systems.

Spencer (37) measured both root dry weight and root-pulling resistance in his estimation of seasonal root development and found these characteristics are positively correlated within inbred lines. In 1970, Zuber, Musick, and Fairchild (45) found that root volume is also highly correlated with root-pulling resistance. Hays and Johnson (13) and Nass and Zuber (28) determined inbred root clump weight and inbred root-pulling resistance to have a highly significant correlation coefficient of .76 and .77, respectively. More recently, Jenison (19) found that root-pulling resistance, root dry weight, root spread, and total root abundance are highly correlated.

The correlations among these characteristics indicate that they estimate similar qualities and that any one of them could be used to determine the quality of a corn root system.

Root characteristics and the relationships between top and root growth become most important when considering their relation to future improvement of corn lines. Corn breeders selecting for traits such as corn rootworm tolerance, root rot resistance, and drought tolerance have used this information to the greatest degree. Investigations revealing the specific root system characteristics responsible for resistance or tolerance to a specific problem have aided in the improvement of corn lines for these traits.

Corn rootworm tolerance as classified by Fitzgerald and Ortman (9) is largely accounted for by four factors: (1) the possession of a strong well-developed root system; (2) the ability to regenerate new roots after feeding damage, particularly under conditions of moisture stress; (3) the time of the insect attack in relation to the developmental stage of the plant; and (4) environmental conditions, especially moisture supply and soil fertility during and after attack. Ortman and Gerloff (32), Zuber (44), and Zuber, Musick, and Fairchild (45) all indicated the importance of the first factor, particularly under light to moderate infestations. Under heavy infestations, the second factor is of greater importance. However, these studies stress this point to a lesser degree due to the difficulties involved in measuring such a trait.

Estimation of the size of the root system has been accomplished in a number of ways. Zuber (44) used root-pulling resistance, root volume, and root clump weight to evaluate root size. Fitzgerald and Ortman (9) and Ortman and Gerloff (32) used root-pulling resistance and root clump weight. In all cases, the sampling of the root system for these characteristics was done after tasseling to allow for maximum root development. Work by Foth (10) indicated that maximum root development is complete very soon after flowering. Mengel and Barber (22) found that after flowering, root death becomes equal to root growth resulting in a more or less constant root system size. Both of these studies reaffirm that this is the best stage for the sampling of the root systems to determine superior root size.

Reduction of yield and increased incidence of lodging in corn lines susceptible to root rot have made root rot resistance of major importance to many plant breeders. Hornby and Ullstrup (16) reported that root rot is caused by a complex of organisms including such fungal genera as *Fusarium* and *Diplodia*. The relationship between the fungal populations of the rhizosphere and the root system is quite complex, making true resistance difficult to obtain.

Several researchers have noted however, that the size of the root system has a definite bearing on the severity with which root rot will affect the plant. Holbert and Koehler (15) found that root rot susceptible lines have smaller, less extensive root systems than lines which are resistant. Semeniuk (34) similarly noted that plants with lower amounts of secondary roots exhibit more yield reduction due to root rot. Nagel, Shank, Dirks, and Kratochvil (27) found similar results, showing that root characteristics such as root abundance and the amount of fine roots, are related to root rot resistance. More recently, Jenison (19) reaffirmed these observations, finding that a significant negative correlation exists between root rot susceptibility and total root abundance (total root mass).

The importance of selecting large root systems in corn inbred lines is clearly shown by these findings. To accomplish such selection, both root-pulling resistance and root digging methods have been used. Root-pulling resistance was first used for this purpose by Holbert and Koehler (15) and later by Jenison (19) to estimate root rot resistance. Nagel (26) however, used a root digging method in which the roots were removed from the soil at harvest and visually graded for root rot resistance and size. Lines developed by Nagel, using this selection method, were found to be significantly superior in their tolerance to corn rootworm damage by Fitzgerald and Ortman (9).

Jenison (19) used both of these methods in his study and found that root-pulling resistance showed a stronger negative correlation with root rot susceptibility than did total root abundance. This suggests that the root-pulling resistance method may be more efficient and subjective in selection for root rot resistance. Ortman, Peters, and Fitzgerald (31) summarized a study comparing visual rating methods to root-pulling resistance by suggesting that "a root-pulling resistance measurement is an efficient means of obtaining quantitative data that should be freer of subjective biases than some other determinations."

Drought tolerance appears to be partially dependent on root system characteristics. Sullivan and Blum (38) discovered that under moderate or short-term drought conditions, a large more profuse root system may serve as an advantage, but such an advantage decreases as drought increases in duration. Norden (30) confirmed their findings, reporting that a large root system is of no advantage during a long-term drought. Sullivan and Blum (38) further reported that during severe drought, plants possessing a smaller root system in conjunction with greater heat and desiccation tolerance are the most desirable.

The results of studies concerning root characteristics are encouraging plant breeders to select stronger, higher volume root systems. As a result of such selection, corn lines possessing rather extensive root systems have been produced. Although we continue to select plants with these qualities, we do not fully understand how such a 'superior' root system may be affecting the plant.

Concern for the ability of a corn inbred line to produce sufficient amounts of pollen for seed production has often led to selection for a large tassel. Diversity in tassel size as measured in terms of dry weight, branch number, or visual ratings has been investigated by several researchers (2,13,24). Several effects of tassel size on the plant have been hypothesized. Dungan and Woodworth (7) suggested that tassels may cause shading of the corn canopy and result in a reduction of the light received by the leaves which could cause a reduction in the rate of photosynthesis in the corn canopy.

Sanford, Grogan, Bruce, Jordan, Myhre, and Sarvella (33) noted that at the time of anthesis, the tassel contains 20 percent of the total nitrogen of the plant and that during the week prior to anthesis, 50 percent of the nitrogen accumulated by the plant is taken by the tassel. The effect of such a nitrogen sink on the plant has been shown by several studies in which yields were increased significantly by tassel removal prior to anthesis (2,12,17,18,24). This yield increase is generally accounted for by the reduction in stress which is put on the developing ear resulting in a reduced amount of silk delay and plant barrenness. Buren, Mock, and Anderson (5) found that corn lines with smaller tassels exhibit a shorter interval between the onset of pollen shed and silking (silk delay) as well as reduced plant barrenness. Tassel size could therefore have a strong influence on plant productivity.

Silk delay, as shown by several investigators (1,8,40), increased with the imposed stress of increased plant population and ultimately reduced yields. Jensen (20) found drought to be highly correlated ($r = .935$) with silk delay and silk delay to be highly correlated with yield reduction. Increases in silk delay under stress may be accentuated by the added drain of a large tassel. Selection for a large tassel may therefore result in counteracting the overall goal of greater yielding ability under stress situations.

The interrelationships of tassel size, silk delay, and root characteristics must be considered in terms of their effect on yield to provide a better understanding of total plant performance. Few studies providing links to tie these factors together have been conducted.

Hays and Johnson (13) provided information on these relationships from 12 inbred characteristics such as root-pulling resistance, root volume, total brace root number, yield, and tassel index (a visual rating of tassel size). These characteristics were observed in 110 inbred lines with correlations between these traits calculated to determine the relationships present. Inbred root-pulling resistance and inbred root volume were found to be significantly correlated ($r = .7623$). Further, inbred root-pulling resistance and inbred tassel index were found to be significantly correlated ($r = .4052$), but inbred tassel index was not found to be significantly correlated with inbred yield. Inbred root-pulling resistance and inbred root volume were similarly found not to be significantly correlated with inbred yield. Surprisingly however, inbred root-pulling resistance and inbred root volume were found to be very significantly correlated with the yield of the F_1 crosses of the involved inbreds, $r = .4486$ and $.5430$, respectively.

Norden (30) found that the root dry weight of a corn line is significantly correlated to the yield of that line ($r = .63$). When considering the strong correlation found between root-pulling resistance and root dry weight by Spencer (37), the contradicting results of these experiments indicate that we are unsure what is actually taking place in the plant.

Very little has been done to determine the effect that a large root system and/or tassel may have on the grain yield of corn. The information that has been accumulated on this relationship is neither in complete agreement nor very recent. The possible implications of the increased selection pressure for root size in the past few years should be explored further in an attempt to better understand the drain which a large root system or tassel may put on a plant, particularly when the plant is subjected to stress.

MATERIALS AND METHODS

Twelve corn inbreds of medium maturity were selected from the 44 lines used by Jenison (19). These inbred lines were selected on the basis of root-pulling resistance and root dry weight data to represent an equal distribution of large, medium, and small size root types. The lines used in this test represent the efforts of the corn breeding programs of the University of Minnesota, South Dakota State University, the University of Wisconsin, the University of Connecticut, and the USDA Northern Grain Insects Laboratory located near Brookings, South Dakota. (See appendix Table A1 for more information about the parental background of the lines.)

In 1976, the 12 inbred lines were crossed in all possible combinations to form a complete set of the possible single cross hybrids (reciprocals were not used). The resulting 66 hybrids were planted at Brookings for two consecutive years (1977 and 1978). In 1977, the study was located at the Plant Pathology farm of the South Dakota State Agricultural Experiment Station on a Linsmore silty clay loam soil. The 1978 test was conducted at the Agronomy farm of the same station on a Vienna loam soil. In both cases, the test was planted on ground which had been summer fallowed the previous year. Normal fertilization rates for the growth of corn on these farms were used both years and no soil insecticide was used in either year.

Each entry was replicated three times in a split plot design and planted at 2 populations per replication. Both high and low populations of each entry formed subplots represented by 1 row plots 7 m long (1 for the high populaton, 1 for the low population for each entry). Kernels were hand planted in 1 m row spacings in 1977 and 1978. In the low population subplots, 2 kernels were planted every 25 cm and in the high population subplots, 2 kernels were planted every 18 cm. When the plants reached 18 to 25 cm in height, the stand was thinned to 1 plant per hill. This resulted in a plant population of approximately 38,500 and 55,300 plants per ha for the low and high populations, respectively. Approximately 15 to 20 days after the original planting, kernels of a purple marker hybrid line were used to replant in places where both kernels of the original seed failed to emerge.

The F_1 hybrids were evaluated for tassel dry weight, silk delay, root system strength and volume (as estimated by root-pulling resistance), and yield. The population levels used in this experiment were planned in hopes of observing the relationship between these characteristics under stress conditions. The recommended planting rate for corn in east central South Daktoa is 34,600 to 39,500 plants per ha. Under a normal year, the high population subplots should have experienced mild to severe stress in terms of moisture and possibly fertilization. This would hopefully accentuate any effect caused by the added strain of a large tassel or root system. However, conditions during the critical periods of the growing season were excellent in both 1977 and 1978, with little or no stress evident on the plants.

Tassel dry weight was determined for each subplot in all three replications for both years. Tassels from 5 consecutive plants, starting with the second plant in from the end of the row, were clipped just below the lowest rachis node.

In 1977, all 5 tassels were placed in a marked pollinating tassel bag, in which holes had been punched for air movement, and stapled shut. All 5 tassels were collected from a given subplot on the same day just prior to pollen shed. The tassels were placed in a dryer shortly after collection and dried at 40 to 45^{o} C to prevent spoilage. When the tassels from all of the subplots had been harvested, the collections were left in the first dryer for a minimum of 4 days to allow all of the tassels to stabilize. The collected tassels were then transferred to another drier and dried for 2 days at 70^{o} C. Each group of tassels was then weighed to obtain a total tassel dry weight. An average tassel dry weight per plant was then calculated for each subplot.

In 1978, the tassels were collected in the same manner as in 1977 except, each tassel was placed in a smaller bag before being placed in the larger bag for the subplot. This allowed the determination of the individual tassel dry weights within the subplot. The tassels were again given the same treatment in drying as in 1977.

Silk delay on each subplot was determined on the basis of 50 percent flowering. The date on which 50 percent of the plants in the subplot were shedding pollen was recorded, as was the date on which 50 percent of the plants were starting to silk. Silk delay was then calculated by subtracting the date of pollen shed from the date of silking. Subplots in which silking occurred before pollen shed received negative values of silk delay.

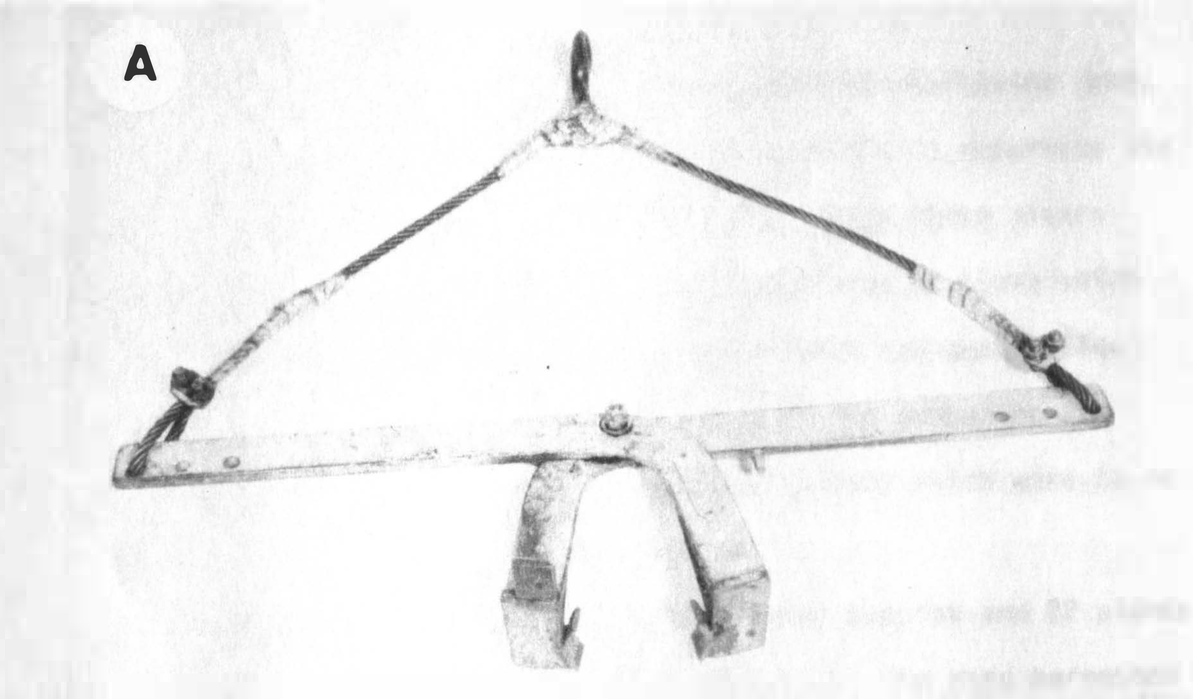
Root-pulling resistance was measured as the kilograms of force required to lift a plant vertically from the soil. Force was exerted through a bar attached from a bipod through a dynamometer to a clamp secured around the base of the plant just above the soil (Figure 1). Root-pulling resistance was determined three weeks after the average silking date of the test (approximately the kernel milk stage). Five plants from each subplot were pulled in each of the three replications. The first plant pulled in each case was the first plant following those plants which had been used in the tassel weight determination. Detasseled plants were not used. Only non-consecutive plants that were bordered on both sides by other plants were used for obtaining root-pulling resistance data. Plants adjacent to a vacant space or another plant that had been pulled were not used.

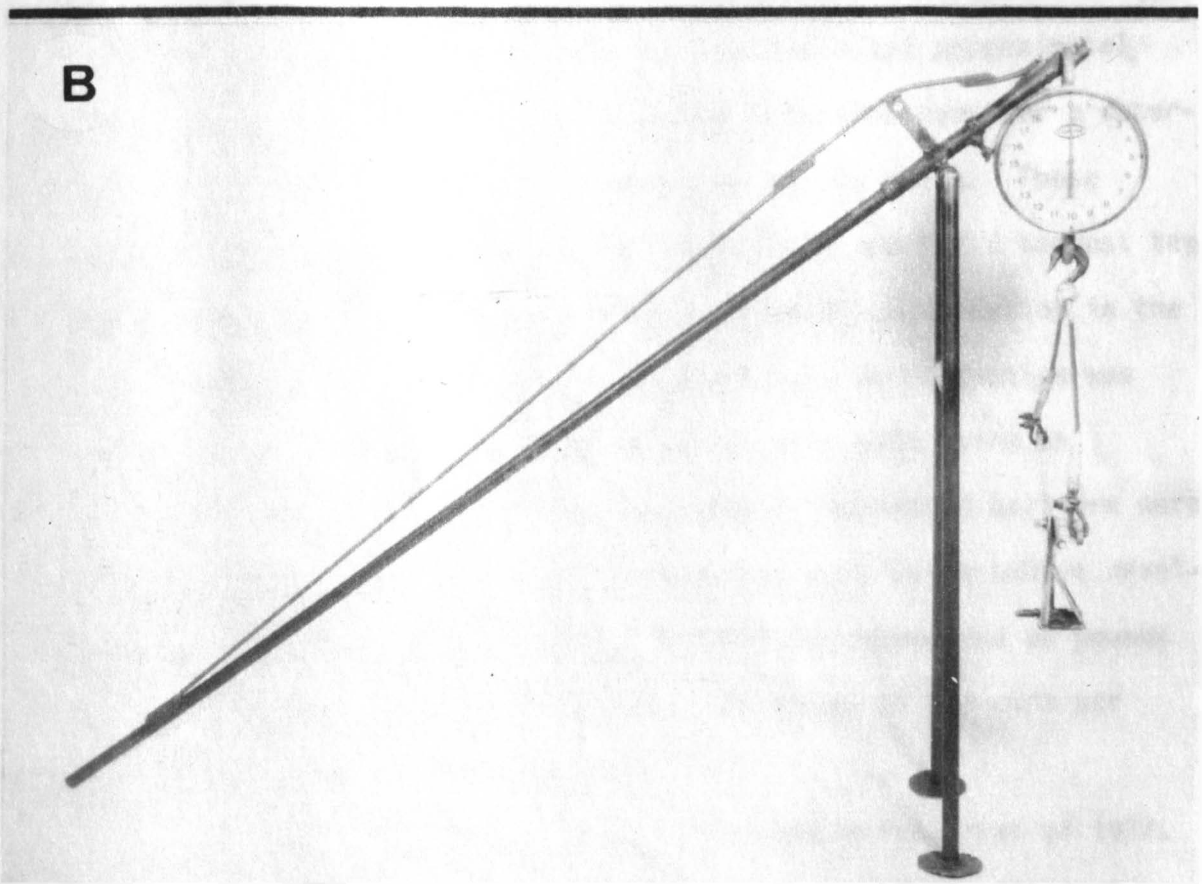
In 1977, the 5 root-pulling resistance values were averaged for the subplot for evaluation of the test. In 1978 however, these values were considered independently for a more detailed analysis to determine the variability existing within a subplot.

Figure 1. Root-pulling apparatus used in this study.

A. Cast-iron clamp which hooks on ring attached to scale of root-pulling apparatus.

B. Complete root-pulling apparatus.


A


B

Following the collection of the root-pulling resistance data, stand counts were taken in the individual subplots to determine the number of competitive plants which remained. Only those plants which were bordered on either side by other plants or those which had been bordered on either side by plants which had been pulled were counted as competitive plants. Based on the number of remaining competitive plants, the number of plants which were to be harvested in each subplot was determined.

In 1977, 13 plants in each low population subplot and 22 plants in each high population subplot were harvested. The hand harvested ears for each subplot were weighed in the field and approximately 200 grams of grain were shelled from the harvested ears for a determination of the field moisture percentage of the grain. These samples were sealed in plastic bags containing the field harvest tag and placed in a cooler at 7 to 10^{o} C to prevent condensation in the bag or drying of the sample until the moisture determination was made. Moisture percentage determinations were made using an electronic moisture meter. Field weights of harvested ear corn were then corrected to 15.5 percent moisture ear corn using tables developed by Kiesselbach (21). Corrected yield was expressed as pounds of ear corn per plot and was converted to grams of ear corn per plant for the analysis of the test.

Harvest of the 1978 test differed slightly from that of 1977. In an effort to make the data collection more uniform, 10 plants were harvested in both the low population and high population subplots in 1978. The ears harvested from each subplot were then handled in the same manner as in 1977, with the final yield for each subplot expressed in terms of grams of ear corn per plant.

An analysis of variance was run for each trait to determine if significant differences were present among lines. Other forms of analysis used to evaluate the data included the calculation of correlation coefficients among the traits and multiple regression using root-pulling resistance, silk delay, and tassel dry weight as independent variables and yield as the dependent variable. As a final analysis of each trait, a diallel analysis was run on the data using Griffing's method (11) to determine general combining ability (G.C.A.) and specific combining ability (S.C.A.).

RESULTS AND DISCUSSION

The overall mean values for silk delay, tassel dry weight, root-pulling resistance, and yield of each F_1 line at both population levels in 1977 and 1978 are shown in Tables 1, 2, 3, and 4.

In determining tassel dry weight, we observed that the length of the internode which supports the main tassel structure varies greatly among lines. To minimize this variability, the tassel is defined as the male flower of the corn plant starting at the lowest rachis node and proceeding to the top of the structure. In accordance with this definition, all tassels were clipped just below the lowest rachis node, as described in the materials and methods section.

Root-pulling resistance determinations were also noted to be affected by the collection methods. Experiments by Foth (10) and Mengel and Barber (22) indicated that maximum root development is achieved at or shortly after flowering. Previous root-pulling resistance data taken on the parent lines by Jenison (19) confirmed their results. Due to this development pattern, root-pulling resistance was determined 3 weeks after the average silking date of the test to reduce the variability between lines to a minimum.

Further steps were taken in the selection of plants for root-pulling to insure a minimum of sampling error. Plants which had been used in the determination of tassel dry weight were avoided due to the possible changes in normal plant growth or translocation of

Table 1. Silk delay means (days) of the 66 F_1 lines.

Entry	1977			1978		
	low*	high*	mean	low*	high*	mean
A619 x A632	.3	3.0	1.7	1.3	1.3	1.3
A619 x A657	1.3	2.3	1.8	0.0	.7	.3
A619 x A659	2.0	2.0	2.0	1.7	1.3	1.5
A619 x A660	3.7	4.0	3.8	1.3	.7	1.0
A619 x C123	2.7	3.7	3.2	1.3	2.0	1.7
A619 x NG72227	2.3	3.7	3.0	1.0	1.0	1.0
A619 x NG72353	1.3	3.7	2.5	1.0	2.0	1.5
A619 x SD30	3.7	4.0	3.8	1.0	1.7	1.3
A619 x SDP309	3.0	3.7	3.3	.7	1.0	.8
A619 x W64A	1.7	3.3	2.5	1.3	1.3	1.3
A619 x W202	.7	2.7	1.7	1.0	0.0	.5
A632 x A657	.3	1.3	.8	-1.3	0.0	-.7
A632 x A659	.3	1.0	.7	-.7	.3	-.2
A632 x A660	1.0	2.0	1.5	1.3	1.3	1.3
A632 x C123	0.0	2.0	1.0	.7	2.0	1.3
A632 x NG72227	.7	1.3	1.0	1.0	1.7	1.3
A632 x NG72353	1.3	2.0	1.7	.7	2.0	1.3
A632 x SD30	1.3	1.3	1.3	1.7	3.0	2.3
A632 x SDP309	1.0	.7	.8	1.3	2.0	1.7
A632 x W64A	.3	1.7	1.0	1.7	2.0	1.8
A632 x W202	1.0	2.3	1.7	2.3	2.3	2.3
A657 x A659	-.3	1.3	.5	-1.7	-.7	-1.2
A657 x A660	.7	1.3	1.0	-.3	.3	0.0
A657 x C123	1.7	2.0	1.8	0.0	1.0	.5
A657 x NG72227	.3	1.3	.8	1.0	1.0	1.0
A657 x NG72353	0.0	.3	.2	-.3	.3	0.0
A657 x SD30	1.0	2.0	1.5	.7	1.3	1.0
A657 x SDP309	.7	1.0	.8	0.0	0.0	0.0
A657 x W64A	.7	1.3	1.0	2.0	1.7	1.8
A657 x W202	1.3	1.0	1.2	1.0	.7	.8
A659 x A660	.7	2.0	1.3	-.3	.7	.2
A659 x C123	1.0	3.7	2.3	1.0	.7	.8
A659 x NG72227	-.3	1.3	.5	-.3	.3	0.0
A659 x NG72353	.7	0.0	.3	.7	1.0	.8
A659 x SD30	2.0	2.0	2.0	2.3	1.7	2.0
A659 x SDP309	1.0	1.3	1.2	1.0	1.0	1.0
A659 x W64A	0.0	1.3	.7	.3	.3	.3
A659 x W202	1.7	2.3	2.0	.7	2.3	1.5
A660 x C123	1.0	2.0	1.5	.3	1.3	.8
A660 x NG72227	2.0	2.0	2.0	1.3	2.3	1.8
A660 x NG72353	1.0	2.0	1.5	1.3	1.0	1.2
A660 x SD30	2.3	2.7	2.5	1.7	3.3	2.5
A660 x SDP309	1.7	1.3	1.5	1.7	1.7	1.7
A660 x W64A	2.0	2.3	2.2	1.7	2.0	1.8
A660 x W202	4.0	3.0	3.5	1.7	1.7	1.7
C123 x NG72227	2.7	2.0	2.3	1.3	1.0	1.2
C123 x NG72353	1.0	1.3	1.2	1.0	1.7	1.3
C123 x SD30	1.7	2.7	2.2	2.0	2.0	2.0
C123 x SDP309	3.0	3.7	3.3	2.7	2.3	2.5
C123 x W64A	.7	1.7	1.2	1.7	2.3	2.0
C123 x W202	1.7	3.3	2.5	1.0	1.3	1.2
NG72227 x NG72353	-.3	0.0	-.2	0.0	.7	.3
NG72227 x SD30	2.0	1.7	1.8	2.0	2.0	2.0
NG72227 x SDP309	1.3	1.0	1.2	1.7	2.0	1.8
NG72227 x W64A	1.7	2.0	1.8	1.7	2.3	2.0
NG72227 x W202	2.0	2.3	2.2	1.7	2.3	2.0
NG72353 x SD30	1.3	2.0	1.7	1.7	2.7	2.2
NG72353 x SDP309	2.3	2.7	2.5	2.0	3.7	2.8
NG72353 x W64A	1.0	1.7	1.3	1.3	2.0	1.7
NG72353 x W202	1.3	2.7	2.0	1.7	2.0	1.8
SD30 x SDP309	2.0	3.0	2.5	2.3	3.3	2.8
SD30 x W64A	1.0	1.7	1.3	1.3	2.0	1.7
SD30 x W202	3.3	3.3	3.3	1.3	1.7	1.5
SDP309 x W64A	2.3	2.7	2.5	1.3	2.7	2.0
SDP309 x W202	2.0	2.3	2.2	2.0	2.0	2.0
W64A x W202	1.7	2.7	2.2	2.0	2.3	2.2
Mean	1.4	2.1	1.8	1.1	1.5	1.3

* population levels.

Table 2. Tassel dry weight means (g) of the 66 F_1 lines.

Entry	1977 low*	1977 high*	1977 mean	1978 low*	1978 high*	1978 mean
A619 x A632	7.75	7.77	7.76	7.99	8.03	8.01
A619 x A657	8.27	5.79	7.03	9.10	7.78	8.44
A619 x A659	9.51	8.01	8.76	9.60	9.04	9.32
A619 x A660	9.19	8.52	8.85	9.44	8.57	9.00
A619 x C123	10.27	9.32	9.80	10.73	9.26	10.00
A619 x NG72227	9.02	3.62	8.82	9.70	9.08	9.39
A619 x NG72353	6.72	6.00	6.36	8.10	7.49	7.79
A619 x SD30	9.94	8.18	9.06	9.51	9.81	9.66
A619 x SDP309	7.74	7.43	7.58	10.09	8.37	9.23
A619 x W64A	8.15	7.69	7.92	8.63	7.58	8.10
A619 x W202	9.63	7.56	8.60	9.40	9.20	9.30
A632 x A657	6.69	5.43	6.06	6.96	6.81	6.89
A632 x A659	7.27	6.89	7.08	7.91	7.93	7.92
A632 x A660	6.90	6.76	7.16	7.76	7.70	7.73
A632 x C123	8.54	8.39	8.46	9.22	7.64	8.43
A632 x NG72227	7.04	6.25	6.65	7.09	7.17	7.13
A632 x NG72353	6.30	5.02	5.66	5.52	5.22	5.37
A632 x SD30	7.62	7.94	7.78	9.10	8.47	8.78
A632 x SDP309	6.83	6.06	6.46	8.55	7.84	8.20
A632 x W64A	6.60	6.44	6.52	7.05	6.68	6.87
A632 x W202	8.55	7.64	8.09	8.06	7.50	7.78
A657 x A659	8.83	7.13	7.89	8.60	8.20	8.40
A657 x A660	9.71	8.92	9.32	9.41	8.78	9.09
A657 x C123	9.94	8.56	9.25	9.73	8.82	9.28
A657 x NG72227	7.75	6.48	7.12	7.94	8.25	8.10
A657 x NG72353	5.91	4.85	5.38	6.42	5.94	6.18
A657 x SD30	8.59	8.37	8.48	9.02	8.38	8.70
A657 x SDP309	7.05	5.40	6.22	8.47	7.47	7.97
A657 x W64A	6.09	6.14	6.12	7.50	6.94	7.22
A657 x W202	10.84	10.08	10.46	10.95	9.24	10.10
A659 x A660	8.46	7.13	7.80	8.66	7.97	8.31
A659 x C123	9.91	9.44	9.67	9.71	10.05	9.37
A659 x NG72227	8.41	7.07	7.74	8.88	8.14	8.51
A659 x NG72353	7.85	6.47	7.21	8.51	8.03	8.27
A659 x SD30	10.39	9.78	10.08	11.05	9.38	10.21
A659 x SDP309	8.38	8.16	8.27	9.45	8.57	9.01
A659 x W64A	8.25	7.56	7.98	8.56	8.06	8.31
A659 x W202	9.68	9.47	9.66	11.12	9.44	10.28
A660 x C123	12.21	9.92	11.07	11.22	9.88	10.55
A660 x NG72227	9.21	7.53	8.37	8.96	8.28	8.62
A660 x NG72353	6.59	5.86	6.22	7.51	6.41	6.96
A660 x SD30	10.25	7.75	9.00	10.97	9.68	10.32
A660 x SDP309	8.17	7.86	8.01	9.38	8.72	9.04
A660 x W64A	9.09	7.67	8.38	8.54	8.28	8.41
A660 x W202	9.64	8.94	9.29	9.56	9.56	9.56
C123 x NG72227	8.75	8.28	8.51	8.52	8.65	8.59
C123 x NG72353	6.76	6.45	6.61	8.08	8.03	8.06
C123 x SD30	10.90	8.66	9.88	11.05	10.07	10.56
C123 x SDP309	9.76	8.51	9.14	10.38	10.69	10.53
C123 x W64A	8.70	7.30	8.00	8.08	7.44	7.76
C123 x W202	13.16	12.22	12.69	12.93	12.45	12.69
NG72227 x NG72353	5.79	5.35	5.57	6.68	7.03	6.85
NG72227 x SD30	8.67	7.01	7.84	8.16	7.39	7.77
NG72227 x SDP309	6.38	6.33	6.36	8.30	8.30	7.82
NG72227 x W64A	6.35	5.02	5.69	6.82	6.48	6.65
NG72227 x W202	8.56	6.39	7.48	7.90	7.88	7.89
NG72353 x SD30	6.60	5.17	5.89	8.49	7.32	7.91
NG72353 x SDP309	6.44	5.79	6.12	7.82	7.24	7.53
NG72353 x W64A	5.62	4.90	5.26	6.67	6.46	6.56
NG72353 x W202	8.25	7.90	8.08	8.86	8.46	8.66
SD30 x SDP309	9.27	8.93	9.10	10.51	8.77	9.64
SD30 x W64A	7.62	6.24	6.93	7.29	6.83	7.06
SD30 x W202	10.32	9.89	10.11	11.66	10.54	11.10
SDP309 x W64A	6.40	6.41	6.40	7.57	7.54	7.55
SDP309 x W202	10.49	9.11	9.80	10.57	9.21	9.89
W64A x W202	9.11	8.44	8.77	8.74	8.19	8.47
Mean	8.39	7.46	7.93	8.86	8.25	8.56

* population levels.

Table 3. Root-pulling resistance means (kg) of the 66 F_1 lines.

Entry	1977 low*	1977 high*	1977 mean	1978 low*	1978 high*	1978 mean
A619 x A632	170.0	159.1	164.6	245.7	200.3	223.0
A619 x A657	190.6	158.7	174.7	259.2	229.7	244.4
A619 x A659	148.9	150.3	149.6	239.0	186.8	212.9
A619 x A660	170.3	155.5	162.9	223.6	182.7	203.1
A619 x C123	206.3	155.5	181.2	215.5	219.7	217.6
A619 x NG72227	169.0	169.2	169.1	234.8	198.0	216.4
A619 x NG72353	198.3	185.1	191.7	251.7	243.7	247.7
A619 x SD30	185.5	153.4	169.5	258.1	241.0	249.5
A619 x SDP309	157.6	153.8	155.7	228.2	182.1	205.2
A619 x W64A	183.7	164.1	173.9	243.8	220.0	231.9
A619 x W202	183.4	169.3	176.3	257.5	203.0	230.2
A632 x A657	173.0	153.0	163.0	239.0	232.3	235.7
A632 x A659	174.2	162.7	168.4	255.9	237.3	246.6
A632 x A660	180.5	183.7	182.1	237.9	234.3	236.1
A632 x C123	194.7	149.2	171.9	266.1	218.7	242.2
A632 x NG72227	207.3	169.1	188.2	263.4	250.7	257.0
A632 x NG72353	184.7	160.9	172.8	242.1	203.5	222.8
A632 x SD30	168.7	145.9	157.3	223.4	232.3	227.9
A632 x SDP309	170.6	171.1	170.9	239.7	234.3	237.0
A632 x W64A	174.0	169.9	167.5	238.2	222.3	230.3
A632 x W202	164.1	150.4	157.2	261.5	229.3	245.4
A657 x A659	188.9	162.3	168.2	252.2	225.7	238.9
A657 x A660	172.2	149.5	161.4	229.3	210.7	220.0
A657 x C123	217.9	162.7	190.3	261.0	231.0	246.0
A657 x NG72227	201.3	174.5	187.9	264.3	262.7	263.5
A657 x NG72353	205.0	185.7	195.4	277.1	249.0	263.0
A657 x SD30	232.5	186.8	209.7	291.7	243.0	267.3
A657 x SDP309	193.0	174.7	183.8	228.7	207.7	218.2
A657 x W64A	203.1	159.7	181.4	252.3	199.0	225.7
A657 x W202	204.9	177.3	191.1	279.2	265.0	272.3
A659 x A660	155.7	133.3	144.5	220.7	198.8	209.7
A659 x C123	189.0	160.1	174.5	278.2	213.3	254.8
A659 x NG72227	181.3	160.5	173.4	268.7	283.7	276.2
A659 x NG72353	204.4	184.5	194.4	226.5	221.3	223.9
A659 x SD30	194.5	188.9	191.7	262.9	242.0	252.5
A659 x SDP309	176.9	153.7	165.3	242.0	220.7	231.3
A659 x W64A	181.9	156.5	169.2	272.3	245.0	258.6
A659 x W202	190.7	179.1	185.4	241.3	234.7	238.0
A660 x C123	189.0	177.3	183.1	263.5	237.0	250.3
A660 x NG72227	204.7	198.3	201.5	276.3	253.5	264.9
A660 x NG72353	197.5	180.8	189.2	245.0	235.3	240.2
A660 x SD30	202.8	188.5	195.6	251.1	234.0	242.6
A660 x SDP309	187.7	160.3	174.0	270.0	235.3	252.8
A660 x W64A	201.3	187.5	194.4	259.7	216.2	237.9
A660 x W202	212.2	190.6	201.4	251.2	224.1	237.7
C123 x NG72227	194.9	182.3	188.6	249.7	227.0	238.3
C123 x NG72353	249.3	190.7	220.0	280.3	250.3	265.3
C123 x SD30	198.5	180.7	193.2	241.9	251.3	246.6
C123 x SDP309	177.1	170.8	173.9	238.0	234.3	236.2
C123 x W64A	185.2	158.2	171.7	241.3	196.1	218.7
C123 x W202	221.3	192.5	206.9	267.4	224.8	246.1
NG72227 x NG72353	203.1	174.9	189.0	268.5	249.3	258.9
NG72227 x SD30	214.7	179.8	197.3	258.5	234.8	246.7
NG72227 x SDP309	207.3	166.9	187.1	258.5	217.3	237.8
NG72227 x W64A	194.9	167.2	181.1	239.4	237.7	238.5
NG72227 x W202	222.8	178.0	200.4	289.5	274.0	281.8
NG72353 x SD30	206.9	177.1	192.0	252.1	218.3	235.2
NG72353 x SDP309	215.1	175.5	195.3	275.7	266.3	271.0
NG72353 x W64A	210.3	162.3	186.3	243.7	213.3	228.5
NG72353 x W202	196.1	168.7	182.4	261.3	238.0	249.7
SD30 x SDP309	211.6	177.3	194.4	228.3	232.3	230.3
SD30 x W64A	186.7	168.0	177.4	231.9	216.0	224.0
SD30 x W202	230.1	190.5	210.3	284.3	245.8	265.0
SDP309 x W64A	182.0	155.3	168.7	230.2	208.7	219.4
SDP309 x W202	187.6	183.9	185.7	263.6	234.0	248.8
W64A x W202	186.4	188.2	187.3	271.3	226.7	249.0
Mean	192.8	169.7	181.3	252.5	228.6	240.6

* population levels.

Table 4. Yield means (g) of the 66 F_1 lines.

Entry	1977 low*	1977 high*	1977 mean	1978 low*	1978 high*	1978 mean
A619 x A632	230.0	134.7	182.4	251.2	184.6	217.9
A619 x A657	183.1	96.8	140.0	234.6	186.1	210.4
A619 x A659	205.8	152.9	179.4	220.9	171.0	196.0
A619 x A660	190.7	90.8	140.7	227.0	174.0	200.5
A619 x C123	222.5	145.3	183.9	234.6	175.6	205.1
A619 x NG72227	180.1	139.2	159.7	213.4	210.6	211.9
A619 x NG72353	202.8	149.8	176.3	230.0	187.7	208.8
A619 x SD30	233.0	127.1	180.1	216.5	181.6	199.0
A619 x SDP309	137.7	140.7	139.2	163.5	157.4	160.4
A619 x W64A	199.8	134.6	167.2	225.5	184.6	205.1
A619 x W202	204.3	116.5	160.4	245.2	171.0	208.1
A632 x A657	216.4	127.1	171.8	204.3	178.6	191.4
A632 x A659	208.8	168.0	188.4	231.5	207.3	219.4
A632 x A660	228.8	174.0	201.4	245.2	207.3	226.3
A632 x C123	289.1	187.7	238.4	242.9	220.9	231.9
A632 x NG72227	234.6	174.0	204.3	224.0	190.7	207.3
A632 x NG72353	196.7	157.4	177.1	177.1	181.6	179.3
A632 x SD30	234.9	166.5	200.7	245.2	201.3	223.2
A632 x SDP309	237.6	168.0	202.8	223.9	205.8	214.9
A632 x W64A	243.6	157.4	200.5	211.8	207.4	209.6
A632 x W202	213.4	171.0	192.2	221.0	187.7	204.3
A657 x A659	219.7	148.3	184.0	230.0	157.4	193.7
A657 x A660	225.8	168.0	196.9	224.0	192.2	208.1
A657 x C123	222.5	155.9	189.2	251.2	189.2	220.2
A657 x NG72227	222.4	181.6	202.0	243.7	196.8	220.2
A657 x NG72353	171.0	154.4	162.7	217.9	184.6	201.3
A657 x SD30	254.2	152.8	203.5	261.8	187.6	224.7
A657 x SDP309	253.7	126.2	189.9	233.1	196.7	214.9
A657 x W64A	210.3	161.9	186.1	240.6	169.5	205.1
A657 x W202	107.4	104.4	105.9	236.1	202.8	219.5
A659 x A660	183.1	152.9	168.0	187.6	158.9	173.3
A659 x C123	243.6	189.2	216.4	260.3	207.4	233.8
A659 x NG72227	240.9	163.4	202.2	251.2	189.2	220.2
A659 x NG72353	208.8	190.7	199.8	237.6	195.2	216.4
A659 x SD30	231.5	149.8	190.7	240.6	166.5	203.6
A659 x SDP309	216.8	164.9	192.4	230.0	190.7	210.4
A659 x W64A	245.2	184.6	214.9	224.0	171.0	197.5
A659 x W202	211.9	168.0	189.9	224.0	157.4	190.7
A660 x C123	250.0	199.7	224.9	246.7	195.2	221.0
A660 x NG72227	195.9	148.3	172.1	254.2	187.6	220.9
A660 x NG72353	230.0	175.5	202.8	231.5	166.5	199.0
A660 x SD30	236.1	184.6	210.4	261.8	222.5	242.1
A660 x SDP309	260.3	197.3	227.8	267.9	217.9	242.9
A660 x W64A	207.3	190.7	199.0	257.3	198.2	227.8
A660 x W202	198.5	140.7	169.6	255.7	169.5	212.8
C123 x NG72227	228.8	184.6	206.7	243.6	192.2	217.9
C123 x NG72353	249.7	190.7	220.2	230.0	195.2	212.6
C123 x SD30	223.9	227.0	225.5	263.3	217.9	240.6
C123 x SDP309	225.5	187.7	206.6	281.5	234.6	258.0
C123 x W64A	254.2	224.0	239.1	242.1	196.8	219.4
C123 x W202	207.3	99.9	153.6	222.5	175.6	199.0
NG72227 x NG72353	201.5	193.7	197.6	239.1	195.2	217.2
NG72227 x SD30	251.2	190.7	220.9	242.1	213.4	227.8
NG72227 x SDP309	248.2	210.4	229.3	219.5	198.2	208.9
NG72227 x W64A	225.5	166.4	196.0	245.2	181.6	213.4
NG72227 x W202	201.3	142.2	171.8	251.2	195.2	223.2
NG72353 x SD30	257.3	205.8	231.6	254.2	207.3	230.8
NG72353 x SDP309	228.5	174.0	201.3	257.3	190.7	224.0
NG72353 x W64A	237.6	190.7	214.2	228.5	181.6	205.1
NG72353 x W202	263.3	178.6	220.9	230.0	168.0	199.0
SD30 x SDP309	239.1	149.8	194.5	275.4	208.9	242.1
SD30 x W64A	207.3	152.8	180.1	214.9	160.4	187.7
SD30 x W202	213.4	146.8	180.1	205.8	155.4	180.8
SDP309 x W64A	231.5	143.8	187.7	211.9	177.0	194.5
SDP309 x W202	236.1	148.3	192.2	243.6	177.1	210.4
W64A x W202	204.3	178.6	191.5	251.2	195.2	223.2
Mean	220.7	162.6	191.7	235.0	188.8	211.9

* population levels.

photosynthate which may have resulted from tassel removal. Plants located next to a vacant space or a plant which had been pulled were avoided because of the biases which may have resulted from noncompetitiveness or root system disturbances caused by pulling the adjacent plant.

The data from 1977 and 1978 were combined and an analysis of variance was run for each trait (Table 5). Significant differences among lines and between populations were noted for silk delay, tassel dry weight, root-pulling resistance, and yield. Years also showed significant differences for all traits except yield.

Interaction between lines and years was found to be significant for all 4 traits. We believe that this significance may be marginal and a result of the degrees of freedom used in the testing of the F value. None of the other interactions among replications, lines, populations, and years were significant. This indicates that the significant differences were valid and not a result of a combination of two or more factors.

The data indicated that 1978 was a better year for corn production in eastern South Dakota than 1977. This is evident by different mean values for silk delay, tassel dry weight, root-pulling resistance, and yield (Tables 1, 2, 3, and 4, respectively). Silk delay decreased substantially and, correspondingly, tassel dry weight, root-pulling resistance, and yield increased in 1978.

The high population level of 55,300 plants per ha was used in hopes of putting stress on the plants. Observations in the field in

Table 5. Mean squares of 4 variables from the analyses of variance.

Source of variation	Degrees of freedom	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
L[a]	65	6.37**	22.80**	2580.70**	3976.55**
R[b]	2	2.98	14.49	3139.87	886.32
L x R	130	.79	.53	339.63	721.36
P[c]	1	66.21*	120.11**	105881.28*	539601.84**
L x P	65	.72	.58	395.11	975.84
R x P	2	2.29	.22	2050.43	1715.48
L x R x P	130	.96	.60	347.79	752.76
Y[d]	1	39.56*	74.37*	698745.97*	81289.60
L x Y	65	2.39**	1.08**	668.77*	1574.10**
R x Y	2	1.33	.94	26946.76	8041.45
L x R x Y	130	.79	.54	469.84	641.15
Y x P	1	3.28	4.84	49.40	7129.20
L x Y x P	65	.69	.54	340.79	634.05
R x Y x P	2	8.09	1.96	5261.29	4474.15
L x R x Y x P	130	.86	.64	289.95	736.82
Total	791				

*, ** Significant at the 5% and 1% levels of probability, respectively.

[a] Lines
[b] Replications
[c] Populations
[d] Years

1977 however, noted only minimal stress on the high population portion of the test in mid-September. This stress was in the form of firing of the lower leaves of the plants, indicating possible nitrogen deficiency. In 1978, no stress was evident on the plants during any part of the growing season. The yields in 1977 and 1978 (Table 4) were substantially higher than the average yield for eastern South Dakota. Such favorable conditions were very different from the average growing season for the area and may have affected the outcome of this experiment. The lack of large differences between population levels may be due to these near optimum conditions, since such conditions would tend to minimize the stress placed on the plant by the increased competition present at a higher population.

The main objective of this study was to determine the relationship which exists among silk delay, tassel dry weight, root-pulling resistance, and yield, particularly when the plant is subjected to stress. Correlation and multiple regression methods were used to analyze the data to detect any possible relationships. Interactions of populations or years with other plant traits may result in misleading correlations when two population levels or years are combined. The populations and years were therefore kept separate in the calculation of the correlation coefficients to maintain the most uniform conditions in each group.

Significant correlations were noted among several characteristics in 1977 and 1978, but none of these correlations are very large

(Tables 6, 7, 8, and 9).

The strongest correlation in 1977 appeared between silk delay and yield at the high population (Table 7). This correlation was much stronger at the high population in 1977 than at the low population. This trend is also present between root-pulling resistance and silk delay as well as root-pulling resistance and tassel dry weight. Silk delay and tassel dry weight also showed a significant correlation in 1977 in both the low and high populations; however, the correlations did not differ greatly between the populations. Similarly, the correlation between root-pulling resistance and yield did not differ greatly between populations.

Correlations calculated among these traits in 1978 (Tables 8 and 9) generally reflect the more favorable growing season. Most of the correlations were reduced in size and in several cases the indicated relationship was greatly reduced in its magnitude. The relationship between silk delay and yield changed from a significant negative correlation in 1977 to a significant positive correlation in 1978 (Tables 6, 7, 8, and 9). When considering the environmental conditions of 1977 vs. those of 1978, the possible causes of silk delay, and how silk delay may be related to yield, this change is neither unexpected nor totally unexplainable. Increases in silk delay are attributed to stress within the plant which causes a slower rate of development for the young ear. Such conditions may also tend to favor yield reduction by causing poor seed set. The slight stress experiences in 1977 would therefore favor a negative

Table 6. Correlation coefficients among 4 plant characteristics. Low population, 1977.

	Tassel dry weight	Root-pulling resistance	Yield
Silk delay	.286**	-.013	-.212**
Tassel dry weight		-.029	-.087
Root-pulling resistance			.183**

Table 7. Correlation coefficients among 4 plant characteristics. High population, 1977.

	Tassel dry weight	Root-pulling resistance	Yield
Silk delay	.207**	-.219**	-.404**
Tassel dry weight		.177*	-.095
Root-pulling resistance			.161*

*, ** Significant at the 5% and 1% levels of probability, respectively.

Table 8. Correlation coefficients among 4 plant characteristics. Low population, 1978.

	Tassel dry weight	Root-pulling resistance	Yield
Silk delay	.095	-.020	.241**
Tassel dry weight		-.045	.103
Root-pulling resistance			.181*

Table 9. Correlation coefficients among 4 plant characteristics. High population, 1978.

	Tassel dry weight	Root-pulling resistance	Yield
Silk delay	.008	.059	.149*
Tassel dry weight		-.022	.016
Root-pulling resistance			.273**

*, ** Significant at the 5% and 1% levels of probability, respectively.

relationship between silk delay and yield. Correspondingly, the superior conditions experienced in 1978 would be expected to reduce the relationship, since a minimal amount of stress was placed on the developing ear.

Multiple regression served as the second type of analysis for the determination of the relationship among silk delay, tassel dry weight, root-pulling resistance, and yield (Table 10). Linear, quadratic, and cubic models were used in the analysis with yield acting as the dependent variable in an attempt to determine how the other 3 traits may affect yield when considered together. The analysis of the combined 1977 and 1978 data indicated that only the linear model of multiple regression was significant.

Silk delay, tassel dry weight, and root-pulling resistance were all found to contribute significantly to the regression coefficient (R^2). The R^2 value of .228 indicates that although these 3 factors are significantly related to yield, each factor alone has very little effect. Results of the multiple regression generally agree with the correlation analyses. In both cases, silk delay, tassel dry weight, and root-pulling resistance were shown to be weakly related to yield.

The absence of strong relationships among these factors is believed to be partially due to the lack of stress on the plants. The existence of strong relationships between silk delay and yield found by previous experiments (20) provide evidence that such relationships do exist. Under more stress, the outcome of this

Table 10. Multiple regression expressing grain yield of corn as a function of silk delay, tassel dry weight, and root-pulling resistance.

Variable*	b	Accumulated R^2
Root-pulling resistance	.38448	.184
Silk delay	-6.99590	.218
Tassel dry weight	2.71228	.228
Intercept	109.00229	

* All variables contributed significantly (.01 level) to the regression coefficient (R^2).

experiment may have been very different.

In hopes of detecting any relationships related to the increased stress caused by population, a second approach to the data was used. Differences were calculated between population levels for each trait in 1977 and 1978. These differences were then used as the basis for an analysis of variance, as well as correlations and multiple regressions.

This approach only confirmed the fact that 'optimum' conditions were present both years. Although population levels were shown to be significantly different in the original analyses, the analyses of variance for these data showed no significant differences among lines for silk delay, tassel dry weight, and root-pulling resistance (Table 11). Yield did show significance, but this was only at the .05 level. These results indicated that the environmental conditions were too good for even this type of analysis to work.

The final portion of the analysis was the determination of the general combining ability (G.C.A.), which estimates additive genetic action, and specific combining ability (S.C.A.), which estimates non-additive genetic action, of the parent lines for silk delay, tassel dry weight, root-pulling resistance, and yield. For this analysis, Griffing's method of diallel analysis was selected based on the advice of Dr. J. W. Dudley, a quantitative geneticist from the Agronomy department at the University of Illinois at Urbana-Champaign. Method 4 (one set of F_1's but neither parents nor reciprocal F_1's included) of Griffing's diallel analysis was used

Table 11. Mean squares from the analyses of variance of 4 variable differences between population levels.

Source of variation	Degrees of freedom	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
L[a]	65	1.43	1.16	790.22	1951.68*
R[b]	2	4.58	.43	4100.87	3430.97
L x R	130	1.93	1.19	695.59	1505.53
Y[c]	1	6.57	9.68	98.80	14258.40
L x Y	65	1.39	1.08	681.58	1268.10
R x Y	2	16.19	3.91	10522.58	8948.30
L x R x Y	130	1.73	1.28	579.90	1473.65
Total	395				

* Significant at the 5% level of probability.

[a] Lines
[b] Replications
[c] Years

for the actual analysis. Due to the way in which the parent lines were selected for this experiment, the fixed model of method 4 was used. This model restricts us to making conclusions concerning the 4 traits to the 12 inbred parent lines only. A review on the use of diallel analysis written by Baker (4) indicates that the validity of inferences about a trait beyond the G.C.A. and S.C.A. of the inbred lines involved is somewhat questionable unless the lines are selected in a prescribed random fashion.

Analysis of the 1977 and 1978 data showed that G.C.A. effects were significant for all 4 traits at both population levels (Tables 12, 13, 14, and 15). Only root-pulling resistance showed a lower degree of significance at the low population in 1978 (Table 14). Specific combining ability effects also showed significance in 1977 over both populations for all 4 traits, but in 1978, only silk delay and yield showed significance for S.C.A. at both populations. Tassel dry weight showed significance for S.C.A. at the low population, but failed to show significance at the high population (Tables 14 and 15). Root-pulling resistance did not show significance for S.C.A. at either population level in 1978.

Additive genetic effects, which are estimated by G.C.A., were important in the expression of all 4 traits. Non-additive genetic actions (dominance, epistasis, and genotype x environment interactions), which are estimated by S.C.A., also proved to be important in the expression of all 4 traits in 1977. The lack of significance for S.C.A. in 1978 for tassel dry weight at the high

Table 12. Observed mean squares for general combining ability (G.C.A.) and specific combining ability (S.C.A.) for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.[1]

Low population, 1977.

Source of variation	d.f.	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	11	3.53**	12.64**	1237.82**	1696.45**
S.C.A.	54	.51**	.50**	183.87**	633.91**
Error	130	.21	.14	38.85	151.05

Table 13. Observed mean squares for general combining ability (G.C.A.) and specific combining ability (S.C.A.) for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.[1]

High population, 1977.

Source of variation	d.f.	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	11	4.25**	10.02**	482.45**	2798.55**
S.C.A.	54	.49**	.70**	140.26**	407.98**
Error	130	.21	.14	38.85	151.05

** Significant at the 1% level of probability.

Table 14. Observed mean squares for general combining ability (G.C.A.) and specific combining ability (S.C.A.) for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

Low population, 1978.

Source of variation	d.f.	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	11	2.40**	9.61**	613.73*	613.36**
S.C.A.	54	.50**	.46*	268.57	412.96**
Error	130	.10	.33	337.21	96.21

Table 15. Observed mean squares for general combining ability (G.C.A.) and specific combining ability (S.C.A.) for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

High population, 1978.

Source of variation	d.f.	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	11	2.77**	6.84**	1013.45**	705.36**
S.C.A.	54	.41**	.39	320.22	236.48**
Error	130	.10	.33	337.21	97.21

*, ** Significant at the 5% and 1% levels of probability, respectively.

population and root-pulling resistance at both populations may have been due to either an interaction with the environment or an instability in the expression of these traits.

The significance of both G.C.A. and S.C.A. for these traits makes it important that we look more critically at the relative amount of each type of genetic action involved in the expression of each trait in these 12 inbreds. Tables 16, 17, 18, and 19 show the variance components for G.C.A. and S.C.A. for each trait. (See appendix Tables A2 - A17 for more information on the G.C.A., G.C.A. variance, and S.C.A. variance of the individual parent lines.) The ratio of these components allows us to determine which genetic action is relatively more important. Large G.C.A./S.C.A. ratios indicate that additive genetic variance is a sizable portion of the total genetic variance. Small G.C.A./S.C.A. ratios indicate that non-additive genetic effects are proportionately more important in the genetic expression of the trait. A low G.C.A./S.C.A. ratio for a given trait may therefore indicate that selection for that trait may not be very effective.

Both silk delay and yield exhibited relatively low G.C.A./S.C.A. ratios in 1977 and 1978 at both population levels (Tables 16, 17, 18, and 19). Tassel dry weight and root-pulling resistance exhibited low ratios in 1977 at both population levels. Both of these characters showed much larger G.C.A./S.C.A. ratios in 1978, supporting the general trend shown by the combining ability analyses of variance. In both cases, G.C.A. was found to be of greater importance than S.C.A.

Table 16. Components of variation for general combining ability (G.C.A.), specific combining ability (S.C.A.), and ratios of G.C.A. variance to S.C.A. variance for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

Low population, 1977.

Source of variation	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	3.66	13.75	1318.87	1699.94
S.C.A.	16.05	19.68	7831.26	26074.23
G.C.A./S.C.A.	.23	.70	.17	.07

Table 17. Components of variation for general combining ability (G.C.A.), specific combining ability (S.C.A.), and ratios of G.C.A. variance to S.C.A. variance for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

High population, 1977.

Source of variation	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	4.45	10.87	487.97	2912.24
S.C.A.	15.45	30.47	5476.26	13874.23
G.C.A./S.C.A.	.29	.36	.09	.21

Table 18. Components of variation for general combining ability (G.C.A.), specific combining ability (S.C.A.), and ratios of G.C.A. variance to S.C.A. variance for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

Low population, 1978.

Source of variation	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	2.53	10.21	304.17	567.77
S.C.A.	21.81	6.94	N.S.	17050.70
G.C.A./S.C.A.	.12	1.47	Large	.03

Table 19. Components of variation for general combining ability (G.C.A.), specific combining ability (S.C.A.), and ratios of G.C.A. variance to S.C.A. variance for 4 characters of the F_1 generation in the diallel crosses of 12 corn inbreds.

High population, 1978.

Source of variation	Silk delay	Tassel dry weight	Root-pulling resistance	Yield
G.C.A.	2.94	7.16	743.87	668.97
S.C.A.	16.77	3.34	N.S.	7520.71
G.C.A./S.C.A.	.18	2.15	Large	.09

The combining ability analyses indicate that selection for silk delay, tassel dry weight, root-pulling resistance, and yield in these lines may be fairly effective, since G.C.A. effects were found to be significant in both 1977 and 1978. Results of this analysis also reveal that S.C.A. is of importance in the expression of silk delay and yield, making combinations of these lines with other inbreds somewhat less predictable. Tassel dry weight and root-pulling resistance however, show some instability in the significance of S.C.A. effects over years. Such a condition may indicate that environmental conditions play a very important role in the expression of these traits.

CONCLUSIONS

The results of this experiment confirm that significant variability exists among the 66 F_1 corn hybrids for the traits silk delay, tassel dry weight, root-pulling resistance, and yield. Although this variability is easily recognized, we still are not completely sure of its significance. We would have to conclude that silk delay, tassel size, and root size did not have a great deal of effect on the yield of a corn line, but the crop was practically free from stress. The high yields present in 1977 and 1978 indicate this and serve as a warning that under 'normal' conditions or stress conditions the relationships noted here may not hold.

Silk delay is the best example for substantiation of this claim. The change in the environmental conditions between 1977 and 1978 is reflected by this trait. It is possible that silk delay is an indicator of stress which effects the plant during the very critical time of flowering. Improved growing conditions in 1978 resulted in an overall decrease in silk delay. This indicates that the stress placed on the developing ear was less under these conditions. The same reduction in stress resulted in a reduction in the size of the correlation of silk delay to the other plant characters of tassel size and yield.

The drain that the tassel places on the plant prior to anthesis (30) places it in direct competition with the developing ear. Such competition would tend to be more evident during a stress situation in which the materials needed by both the ear and the tassel would be in short supply. Under these conditions, a much stronger relationship may be noted between silk delay and tassel size. The presence of a higher correlation between these characters in 1977, when conditions were slightly less favorable, may serve as evidence to support this theory.

The strong negative correlation between silk delay and yield (r = -.935) shown by Jensen (20) is quite different from the correlation here. This weaker relationship is further evidence of the effect of the exceptional growing conditions experienced during this experiment. This particular difference substantiates the idea that under more severe conditions, much stronger relationships may have been noted.

Root-pulling resistance appears to have very little effect on yield. Although correlation and multiple regression analyses showed that root-pulling resistance did have a significant effect on yield, the actual effect of this trait was relatively small with respect to the total variability in yield. The results would indicate that a large, profuse root system does not adversely affect yield. Even though this is indicated, stress conditions may drastically change the results.

Burstrom (6) indicates that there is no voluntary relationship between root and top growth. The relationships or ties between root and top growth would include compounds which are produced by one but needed by both. Tryptophane is an example of such a compound, since it is believed that the roots are unable to synthesize it. Tryptophane serves as both a component of protein and the mother substance of indole acetic auxins which are directly related to flower development. Under stress conditions, production of tryptophane may be significantly reduced. The resulting increase in competition between the root system and the developing ear for tryptophane may result in a rather significant effect on silk delay and ultimately on the yield of the plant.

The concern of developing too large of a root system may be partially due to the appearance of some existing lines which show exceptional root system characteristics but also show poor yielding ability under stress. It may be possible that selection for a 'superior' root system has been conducted with little or no concern for the yield of the plant. Even when a line is being selected as a source of superior root characteristics for breeding programs, the breeder must remember that the yielding ability of the line will strongly affect its usefullness in the improvement of other inbreds. An intense concern for the improvement of one trait, may actually cause future problems due to the neglect of other important plant characters which may form an inbuilt weakness in the new corn line. Such a weakness may not appear during the 'normal' or above average growing season, but may result in severe unforseen problems when the line is subjected to stress. Dependence on tryptophane by both the root and top growth of the plant could be a limiting factor that would reveal itself during a stress period. By selecting for both yield and root quality, we may prevent this or another compound from becoming a limiting factor in a corn line. In essence, this means that although strong relationships may appear between plant characters when the plant is subjected to stress, these relationships may be partially due to our own neglect during the selection processes used in the formation of the involved inbred lines.

The combining ability analyses revealed that G.C.A. effects were significant for all 4 traits in these corn inbred lines. If this is the case which exists among most corn inbred lines, the possibility of selecting lines which are superior in terms of silk delay, tassel size, root size, and yield are good. The relationships among these characteristics are still unclear and much more work must be done before we will understand how these traits interrelate under stress conditions. More extensive studies conducted under such conditions should provide a clearer picture. The near optimum conditions experienced during this test were actually counterproductive to this study. When provided the necessary moisture and nutrients, the demand for photosynthate, minerals, and other compounds in the plant is very nearly equal to the available supply, resulting in no adverse effect on yield. Such conditions are not always the case. We should therefore further investigate root-top relationships to provide the necessary knowledge for the production of lines which are truly 'superior' producers under stress conditions.

LITERATURE CITED

1. Anderson, I. C. 1967. Plant characteristics that affect yield. Pro. Ann. Corn Sorghum Res. Conf. 22:71-74.

2. Anderson, I. C. 1970. Possible practical applications of chemical pollen control in corn and sorghum seed production. Pro. Ann. Corn Sorghum Res. Conf. 26:22-26.

3. Andrew, R. H. and S. S. Solanki. 1966. Comparative root morphology for inbred lines of corn as related to performance. Agron. J. 58:415-418.

4. Baker, R. J. 1978. Issues in diallel analysis. Crop Sci. 18:533-536.

5. Buren, L. L., J. J. Mock, and I. C. Anderson. 1974. Morphological and physiological traits in maize associated with tolerance to high plant density. Crop Sci. 14:426-429.

6. Burstrom, H. G. 1965. Physiology of plant roots. pp. 154-165. In K. Baker and W. Synder (ed.) Ecology of soil-borne plant pathogens: Prelude to biological control. University of California Press. Berkeley, Los Angeles.

7. Dungan, G. H. and C. M. Woodworth. 1939. Loss resulting from pulling leaves with tassels in detasseling corn. J. Amer. Soc. Agron. 31:872-875.

8. El-Lakany, M. A. and W. A. Russel. 1971. Relationship of maize characters with yield in testcrosses of inbreds at different plant densities. Crop Sci. 11:698-701.

9. Fitzgerald, P. J. and E. E. Ortman. 1964. Breeding for resistance to western corn rootworm. Pro. Ann. Corn Sorghum Res. Conf. 19:46-53.

10. Foth, H. D. 1962. Root and top growth of corn. Agron. J. 54:49-52.

11. Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9:463-493.

12. Grogan, C. O. 1956. Detasseling response in corn. Agron. J. 48:247-249.

13. Hays, H. K. and I. J. Johnson. 1939. The breeding of improved selfed lines of corn. J. Amer. Soc, Agron. 31:710-724.

14. Harvey, P. H. 1939. Hereditary variation in plant nutrition. Genetics 24:437-461.

15. Holbert, J. R. and B. Koehler. 1924. Anchorage and extent of corn root systems. J. Agric. Res. 27:71-78.

16. Hornby, D. and A. J. Ullstrup. 1967. Fungal populations associated with maize roots. Quantitative rhizosphere data for genotypes differing in root rot resistance. Phytopathology 57:869-875.

17. Hunter, R. B., T. B. Daynard, D. J. Hume, J. W. Tanner, J. D. Curtis, and L. W. Kannenberg. 1969. Effect of tassel removal on grain yield of corn (Zea mays L.). Crop Sci. 9:405-406.

18. Hunter, R. B., C. G. Mortimore, and L. W. Kannenberg. 1973. Inbred maize performance following tassel and leaf removal. Agron. J. 65:471-472.

19. Jenison, J. R. 1976. The effect of various root characteristics on root-pulling resistance of 44 inbred lines of corn. M.S. Thesis, South Dakota State University Library, Brookings, South Dakota.

20. Jensen, S. D. 1971. Breeding for drought and heat tolerance in corn. Pro. Ann. Corn Sorghum Res. Conf. 26:198-208.

21. Kiesselbach, T. A. 1950. Progressive development and seasonal variations of the corn crop. University of Nebraska Agr. Exp. Sta. Research Bulletin 166.

22. Mengel, D. B. and S. A. Barber. 1974. Development and distribution of corn root systems under field conditions. Agron. J. 66:341-344.

23. Mengelsdorf, P. C. and S. F. Goodsell. 1929. The relation of seminal roots to corn yield and various seed, ear, and plant characters. J. Amer. Soc. Agron. 21:52-67.

24. Mock, J. J. and S. H. Schuetz. 1974. Inheritance of tassel branch number in maize. Crop Sci. 14:885-888.

25. Musick, G. J., M. L. Fairchild, V. L. Fergason, and M. S. Zuber. 1965. A method of measuring root volume in corn (Zea mays L.). Crop Sci. 5:601-602.

26. Nagel, C. M. 1973. Techniques and methods useful in the selection of root and stalk root resistance in corn. Pro. Ann. Corn Sorghum Res. Conf. 28:51-56.

27. Nagel, C. M., D. B. Shank, V. A. Dirks, and D. E. Kratochvil. 1959. Relation of root rot and root type on yield and maturity of maize. Maize Genet. Coop. Newsletter 33:113-114.

28. Nass, H. G. and M. S. Zuber. 1971. Correlation of corn (Zea mays L.) roots early in development to mature root development. Crop Sci. 11:655-658.

29. Norden, A. J. 1964. Response of corn (Zea mays L.) to population, bed height, and genotype on poorly drained sandy soil. I. Root development. Agron. J. 56:269-273.

30. Norden, A. J. 1966. Response of corn (Zea mays L.) to population, bed height, and genotype on poorly drained sandy soil. II. Top growth and root relationships. Agron. J. 58:299-302.

31. Ortman, E. E., D. C. Peters, and P. J. Fitzgerald. 1968. Vertical-pull technique for evaluating tolerance of corn root systems to northern and western corn rootworm. J. Econ. Entomol. 61:373-375.

32. Ortman, E. E. and E. D. Gerloff. 1970. Rootworm resistance: Problems in measuring and its relationship to performance. Pro. Ann. Corn Sorghum Res. Con. 25:161-174.

33. Sanford, J. O., C. O. Grogan, R. R. Bruce, A. V. Jordan, D. L. Myhre, and P. A. Sarvella. 1964. Nitrogen distribution in corn strains as affected by male sterile cytoplasm. Pro. Ass. S. Agr. Workers 61:68-69.

34. Semeniuk, G. 1959. Root rot and yield of corn in rotations. Phytopathology 49:550.

35. Shank, D. B. 1943. Top-root ratios of inbred and hybrid maize. J. Amer. Soc. Agron. 35:976-987.

36. Smith, L. H. and E. H. Walworth. 1926. Seminal root development in corn in relation to vigor of early growth and yield of the crop. J. Amer. Soc. Agron. 18:1113-1120.

37. Spencer, J. T. 1940. A comparative study of the seasonal root development of some inbred lines and hybrids of maize. Agron. J. 61:521-538.

38. Sullivan, C. Y. and A. Blum. 1970. Drought and heat resistance of sorghum and corn. Pro. Ann. Corn Sorghum Res. Conf. 25:55-66.

39. Thompson, D. L. 1968. Field evaluation of corn root clumps. Agron. J. 60:170-172.

40. Troyer, A. F. 1967. Yield as influenced by maturity and population. Pro. Ann. Corn Sorghum Res. Conf. 22:91-96.

41. Weihing, R. M. 1935. Comparative root development of regional types of corn. J. Amer. Soc. Agron. 27:526-537.

42. Whaley, G. W., C. Heimsch, and G. S. Rabideau. 1950. The growth and morphology of two maize inbreds and their hybrids. Amer. J. Bot. 37:77-84.

43. Wilson, H. K. 1930. Plant characters as indices in relation to the ability of corn strains to withstand lodging. J. Amer. Soc. Agron. 22:435-458.

44. Zuber, M. S. 1968. Evaluations of corn root systems under various environments. Pro. Ann Corn Sorghum Res. Conf. 23:67-75.

45. Zuber, M. S., G. J. Musick, and M. L. Fairchild. 1971. Method of evaluating corn strains for tolerance to western corn rootworm. J. Econ. Entomol. 64:1514-1518.

APPENDIX

Table A1. Line numbers and parentage of the 12 inbred corn lines used in the 1977-78 study.

Inbred	Parentage
A619	(A171 x Oh43) Oh43
A632	(Mt42 x B14) $B14_3$
A657	Iowa Stiff Stalk Synthetic
A659	Minnesota Synthetic 3
A660	Minnesota Synthetic 3
C123	(C102 x C103)
NG72227	(B57 x SD10)
NG72353	(B69 x A251)
SD30	Pioneer 3558
SDP309	(K63 x SDP236)
W64A	(WF9 x 187-2)
W202	Corn Borer Synthetic (Iowa)

Table A2. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for silk delay.

Low population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	.7333	.5188	.6942
A632	-.9667	.9154	.1982
A657	-.7667	.5688	.0142
A659	-.5667	.3021	.0942
A660	.5333	.2654	.4582
C123	.3333	.0921	.4662
NG72227	-.0667	-.0146	.3142
NG72353	-.5667	.3021	.1942
SD30	.5333	.2654	.1782
SDP309	.4333	.1688	.0782
W64A	-.1667	.0088	.0862
W202	.5333	.2654	.4382

Table A3. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for silk delay.

High population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	1.4000	1.9410	.2402
A632	-.5000	.2310	.0722
A657	-1.0000	.9810	.0122
A659	-.6000	.3410	.4802
A660	.1000	.0090	.1402
C123	.6000	.3410	.6202
NG72227	-.5000	.2310	.1522
NG72353	-.4000	.1410	.6802
SD30	.4000	.1410	.0002
SDP309	.1000	.0090	.5402
W64A	.00	.0190	.0722
W202	.4000	.1410	.0802

Table A4. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for silk delay.

Low population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-.1000	.0011	.3355
A632	-.2000	.0311	.2395
A657	-1.0000	.9911	.5075
A659	-.8000	.6311	.8595
A660	.00	-.0089	.1475
C123	.1000	.0011	.3755
NG72227	.1000	.0011	.1955
NG72353	.00	-.0089	.1875
SD30	.6000	.3511	.3955
SDP309	.4000	.1511	.3555
W64A	.4000	.1511	.5355
W202	.5000	.2411	.2275

Table A5. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for silk delay.

High population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-.3667	.1255	.3662
A632	.0333	-.0078	.1262
A657	-.9667	.9255	.4662
A659	-.8667	.7422	.3862
A660	.0333	-.0078	.1662
C123	.0333	-.0078	.1462
NG72227	-.0667	-.0045	.1422
NG72353	.3333	.1022	.4342
SD30	.8333	.6855	.1342
SDP309	.5333	.2755	.3862
W64A	.3333	.1022	.2542
W202	.1333	.0089	.3462

Table A6. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for tassel dry weight.

Low population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	.3918	.1407	.0915
A632	-1.2182	1.4711	.1834
A657	-.2602	.0549	.2486
A659	.4668	.2051	.2852
A660	.7148	.4982	.7185
C123	1.6628	2.7522	.6049
NG72227	-.6342	.3893	.2337
NG72353	-1.9442	3.7669	.3774
SD30	.7898	.6110	.1085
SDP309	-.5362	.2746	.2193
W64A	-1.0292	1.0463	.2110
W202	1.5958	2.5339	.6579

Table A7. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for tassel dry weight.

High population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	.2782	.0646	.8022
A632	-.7518	.5524	.1725
A657	-.4958	.2330	.8904
A659	.5102	.2474	.2800
A660	.4752	.2130	.4604
C123	1.4942	2.2197	.3940
NG72227	-.7778	.5922	.6273
NG72353	-1.8248	3.3172	.1542
SD30	.5812	.3249	.6128
SDP309	-.2118	.0320	.2464
W64A	-.8298	.6758	.2553
W202	1.5532	2.3995	1.1963

Table A8. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for tassel dry weight.

Low population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	.4838	.2038	.1077
A632	-1.2242	1.4683	-.0490
A657	-.3352	.0821	-.0168
A659	.4598	.1812	.0877
A660	.3958	.1264	.1234
C123	1.2198	1.4578	.2477
NG72227	-.8502	.6925	.2067
NG72353	-1.4792	2.1577	-.0969
SD30	.9358	.8455	.2210
SDP309	.3638	.1021	-.1877
W64A	-1.2002	1.4101	.0914
W202	1.2298	1.4823	.6588

Table A9. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for tassel dry weight.

High population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	.3442	.0882	-.0566
A632	-.9778	.9259	.0097
A657	-.4158	.1427	-.0890
A659	.4042	.1331	-.1027
A660	.3062	.0635	.0128
C123	1.2212	1.4610	.3966
NG72227	-.4118	.1393	.1419
NG72353	-1.3138	1.6959	-.0058
SD30	.5872	.3145	.0621
SDP309	.1952	.0078	-.0943
W64A	-1.0288	1.0282	.0399
W202	1.9002	1.1582	.3557

Table A10. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for root-pulling resistance.

Low population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-15.7349	244.0249	96.5653
A632	-15.9148	249.7202	142.5464
A657	6.1452	34.2023	104.9957
A659	-13.4548	177.4711	56.1672
A660	-4.7048	18.5743	132.8843
C123	10.2252	100.9930	246.2755
NG72227	8.0351	61.0022	133.1586
NG72353	14.9751	220.6935	181.6013
SD30	11.1552	120.8770	166.4674
SDP309	-5.4448	26.0851	84.1052
W64A	-3.1448	6.3289	68.2265
W202	7.8651	58.2994	156.3564

Table A11. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for root-pulling resistance.

High population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-9.3132	83.1744	41.5849
A632	-10.1132	98.7148	149.0324
A657	-2.2231	1.3814	55.5800
A659	-7.5232	53.0372	158.9249
A660	3.8168	11.0072	261.6267
C123	1.2868	-1.9050	27.4231
NG72227	5.3568	25.1347	31.5264
NG72353	7.9068	58.9571	104.3681
SD30	6.9768	45.1151	99.2488
SDP309	-2.3832	2.1185	26.2258
W64A	-3.9231	11.8301	53.7347
W202	10.1368	99.1947	86.9598

Table A12. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for root-pulling resistance.

Low population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-12.0365	113.9660	-116.7471
A632	-6.4565	10.7750	-159.5543
A657	5.6535	1.0511	-29.6169
A659	-1.7765	-27.7553	73.6458
A660	-4.8965	-6.9355	27.5210
C123	2.5435	-24.4416	-16.9553
NG72227	9.3835	57.1389	-158.4547
NG72353	4.6535	-9.2559	-50.3979
SD30	.6735	-30.4575	7.2607
SDP309	-7.4665	24.8371	-43.3706
W64A	-5.3365	-2.4326	-106.7885
W202	15.0635	195.9972	-162.7265

Table A13. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for root-pulling resistance.

High population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-20.7498	399.6443	169.7791
A632	-1.9199	-27.2251	-146.0591
A657	4.1302	-13.8525	-64.8848
A659	-.5199	-30.6408	82.9568
A660	-5.2599	-3.2449	-86.7884
C123	-1.0999	-29.7014	-94.6992
NG72227	17.4202	272.5515	121.7307
NG72353	7.3801	23.5549	126.3596
SD30	7.6301	27.3080	-98.6458
SDP309	-4.1499	-13.6897	20.8396
W64A	-11.3498	97.9077	-47.7604
W202	8.4902	41.1719	-164.3616

Table A14. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for yield.

Low population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-23.7881	552.0293	510.3457
A632	10.6218	98.9764	267.1125
A657	-15.1181	214.7115	966.0859
A659	-1.1582	-12.5050	191.7885
A660	-2.1182	-9.3597	250.8112
C123	18.9418	344.9470	237.7799
NG72227	.2719	-13.7224	137.8092
NG72353	1.9519	-10.0366	588.2087
SD30	15.4218	233.9868	301.5996
SDP309	7.7319	45.9354	678.8845
W64A	3.8918	1.3000	73.7131
W202	-16.6482	263.3147	1014.0254

Table A15. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for yield.

High population, 1977.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-35.9898	1281.4219	110.3730
A632	-.2498	-13.7840	53.9742
A657	-20.0898	389.7534	89.4077
A659	4.4402	5.8687	74.4719
A660	3.4202	-2.1487	327.3599
C123	20.3402	399.8770	552.0303
NG72227	10.6202	98.9419	223.2043
NG72353	17.3002	285.4500	18.7608
SD30	6.5401	28.9266	250.9460
SDP309	3.2801	-3.0870	242.9997
W64A	9.7201	80.6349	284.0681
W202	-19.3298	359.7947	549.7336

Table A16. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for yield.

Low population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-12.2815	141.9238	574.5635
A632	-10.7115	105.8259	339.6855
A657	-.7915	-8.2843	55.8254
A659	-4.7215	13.3819	252.5353
A660	7.3985	45.8270	341.6233
C123	13.3485	169.2708	144.7708
NG72227	4.1985	8.7166	55.2662
NG72353	-5.2015	18.1447	241.5246
SD30	9.6384	83.9888	324.6851
SDP309	2.2385	-3.9001	688.4512
W64A	-3.2215	1.4673	134.0451
W202	.1085	-8.8991	259.9412

Table A15. General combining ability (G.C.A.), G.C.A. variance, and specific combining ability (S.C.A.) variance of the 12 parent corn inbred lines for yield.

High population, 1978.

Line	G.C.A.	G.C.A. variance	S.C.A. variance
A619	-9.2714	77.0484	126.0205
A632	9.6585	84.3757	58.6062
A657	-3.5115	3.4195	91.7412
A659	-10.4914	101.1594	126.6762
A660	1.2886	-7.2504	171.5070
C123	12.3685	144.0695	116.0208
NG72227	7.3785	45.5321	71.3535
NG72353	-2.3314	-3.4752	60.0956
SD30	4.6285	12.5126	222.2643
SDP309	7.8086	52.0628	147.4151
W64A	-5.3615	19.8344	135.9492
W202	-12.1615	138.9902	178.7726